Advection-Dominated Accretion and Black Hole Event Horizons

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ABSTRACT

The defining characteristic of a black hole is that it possesses an event horizon through which matter and energy can fall in but from which nothing escapes. Soft X-ray transients (SXTs), a class of X-ray binaries, appear to confirm this fundamental property of black holes. SXTs that are thought to contain accreting black holes display a large variation of luminosity between their bright and faint states, while SXTs with accreting neutron stars have a smaller variation. This difference is predicted if the former stars have horizons and the latter have normal surfaces.

Subject headings: accretion, accretion disks — binaries: close — black hole physics — X-ray binaries

1. Introduction

Soft X-ray transients (SXTs) are binary stellar systems in which a black hole (BH) or neutron star (NS) primary accretes matter from a main sequence or giant secondary (van Paradijs & McClintock 1995; Tanaka & Shibazaki 1996). A typical SXT displays a large variation in luminosity. Most of the time it remains in a quiescent state and is very dim. In this phase, only a fraction of the mass transferred from the secondary accretes on the primary, the rest being stored in the outer part of an accretion disk. Once every few decades, however, the source goes into outburst and becomes very bright for a few months. During this time, the material stored in the outer disk is apparently accreted very rapidly.

In addition to the major outbursts described above, some SXTs also display Type I bursts due to thermonuclear flashes of the accreted material, which unambiguously identifies them as NS SXTs (Joss & Rappaport 1984). In a few of these systems the mass of the primary star has been measured and found to be consistent with the mass of a NS ($\sim 1.4 M_{\odot}$). In several other SXTs, however, the mass of the primary is found to be $> 3M_{\odot}$, which makes these stars too massive to be NSs. These are identified as BH candidates.

Although BHs and NSs have been convincingly distinguished on the basis of their masses, we note that the real physical distinction between the two is that BHs are supposed to have event horizons while NSs are normal stars with surfaces. This basic difference between BHs and NSs has not so far been demonstrated. We show in this paper that SXTs provide a unique opportunity to test the reality of event horizons. Since our argument depends on an understanding of accretion flows, we begin with a discussion of this subject in §2.

2. Models of Accretion Flows

A standard paradigm in the field of accretion is the thin accretion disk (Frank, King & Raine 1992). In this model, the heat energy released by viscous dissipation is radiated almost immediately by the accreting gas, and so the net luminosity is equal to (approximately one half) the gravitational energy released as the mass falls onto the central star. Since the effective radius of a BH, namely the Schwarzschild radius R_S ($= 2GM/c^2$, where M is the mass of the BH), is not very different from the radius of a neutron star, $R_{NS} \sim 10$ km $\sim 2.5 R_S$ (Shapiro & Teukolsky 1983), the depth of the gravitational potential is roughly the same for the two stars. Therefore, the accretion luminosities are also nearly equal, corresponding to $\sim 10\%$ of the rest mass energy of the accreting gas, i.e. $L \sim 0.1\dot{M}c^2$, where $\dot{M}$ is the mass accretion rate.

SXTs in outburst appear to be reasonably well described by the thin accretion disk model. The spectra are compatible with this model, though there are some components in the spectra (e.g. a hard power-law tail in the case of the BH SXTs) which suggest that a part of the accretion may be in a form other than a thin disk (Tanaka & Shibazaki 1996). The maximum luminosities L_{max} seen in SXTs at the peaks of their outbursts are $\sim (0.2 - 1)L_{Edd}$, where $L_{Edd} \sim 10^{38}(M/M_\odot)$ erg s^{-1} is the Eddington luminosity. This suggests that SXTs approach the Eddington mass accretion rate $\dot{M}_{Edd} \sim 1.4 \times 10^{18}(M/M_\odot)$ g s^{-1} in outburst. BHs in SXTs typically have masses $\sim 5 - 15 M_\odot$, which makes them several times more massive than NSs. Therefore, we expect larger values of L_{max} in BH SXTs than in NS SXTs.

BH SXTs in quiescence are not well described by the thin accretion disk model. The spectra of two well-observed systems, A0620–00 and V404 Cyg, are impossible to explain using a thin disk (Narayan, McClintock & Yi 1996; Narayan, Barret & McClintock 1997), and it appears that a different model is required.

In recent years, considerable work has been done on advection-dominated accretion flows (ADAFs) which represent a very different regime of accretion than the thin disk (Narayan & Yi 1994, 1995; Abramowicz et al. 1995; Chen et al. 1995; see Rees et al. 1982 for a discussion of the related ion torus model). The key feature of an ADAF is that the radiative efficiency of the accreting gas is low, so that the bulk of the viscously dissipated energy is stored in the gas as thermal energy (or entropy). ADAF solutions exist below a critical accretion rate, $\dot{m} < \dot{m}_{crit} \sim 10^{-2} - 10^{-1}$, where we define $\dot{m} \equiv \dot{M}/\dot{M}_{Edd}$.

The optically thin gas in an ADAF radiates with a spectrum which is very different from the blackbody-like spectrum of a thin disk, and the two modes of accretion are easy to distinguish via observations. More importantly for the purpose of this paper, the luminosity of an ADAF has a steep dependence on $\dot{m}$, viz. $L/L_{Edd} \equiv l \sim \dot{m}^2/\dot{m}_{crit}$ (Narayan & Yi 1995; Mahadevan 1997). The quadratic scaling with $\dot{m}$ arises because the gas is in the form of a two-temperature plasma with the ions being much hotter than the electrons (Shapiro, Lightman & Eardley 1976). The efficiency with which thermal energy is transferred from ions to electrons (to be subsequently radiated) is proportional to $\dot{m}$, and therefore $l \propto \dot{m}^2$ (Rees et al. 1982). In contrast, the luminosity of a thin disk varies as $l \sim \dot{m}$. The variation of luminosity with $\dot{m}$ in the two regimes of accretion is indicated by the solid line in Fig. 1. Note that the total energy released by gravity is always $L_{release}/L_{Edd} \sim \dot{m}$. The key difference is that whereas in a thin disk a large fraction of the released energy is radiated, in an ADAF nearly all the energy remains locked up in the gas as thermal energy and is advected into the central star. If the star happens to be a BH, the advected thermal energy disappears through the horizon.

The observed quiescent spectra of the BH SXTs, A0620–00 and V404 Cyg, are explained well with

an ADAF model (Narayan et al. 1996, 1997). The ADAF extends from the horizon of the BH out to a radius $\sim 10^4 R_S$, and a thin disk is present outside this radius. The model is consistent with all the spectral information available at this time.

When an ADAF encounters a BH, an enormous quantity of thermal energy disappears through the event horizon; the energy flow rate into the BH is $\sim 0.1\dot{M}c^2$. Since the horizon plays such a crucial role, the success of the ADAF model in the case of A0620–00 and V404 Cyg indicates that these two BH candidates at least are true black holes with horizons (Narayan et al. 1996, 1997).

What do we expect in the case of a NS SXT? It is reasonable to assume that, in quiescence, these systems too undergo accretion via ADAFs. As in BH SXTs, the accreting gas would radiate very inefficiently, and the direct luminosity from the accretion flow would be very low ($l \sim \dot{m}^2/\dot{m}_{crit}$). However, when the superheated gas falls on the NS, the thermal energy does not disappear but rather heats up the star. Once a steady state is reached, we would expect the stellar surface to radiate with a luminosity equal to the rate at which thermal energy flows into it. Thus, the total observed luminosity will be the same as in a thin disk, i.e. $l \sim \dot{m}$ (Narayan & Yi 1995), as indicated by the dashed line in Fig. 1.

The comparison shown in Fig. 1 implies that the spread of luminosity between the outburst and quiescent state in BH SXTs (solid line) should be significantly larger than the spread in NS SXTs (dashed line). In the next section we discuss the observations we have collected in order to test this prediction.

3. Observations

The observations of SXTs listed in Table 1 yield the quiescent luminosities listed in Table 2. In order to make an unbiased comparison of the high and low state luminosities, we have taken the fluxes from the literature and/or archival data from the HEASARC in order to compute the emitted luminosities over the 0.5–10.0 keV band. In computing the quiescent luminosities, we have been motivated by two points. First, the only BH SXT with a well-determined quiescent spectrum is V404 Cyg (Narayan et al. 1997). Its observed spectrum is a power-law with a photon index $\alpha_N \approx 2.1$ (0.7–8.5 keV), a result that is in excellent agreement with the prediction of the ADAF model (Narayan et al. 1997). Consequently, in deriving the quiescent luminosity of A0620–00 and the luminosity limits for the three fainter BH SXTs, we assume that their spectra also have a power-law form with $\alpha_N = 2.1$. Second, the existence of the neutron star surface gives some physical motivation to a blackbody spectral shape which we assume (and which is generally consistent with the data) for the NS SXTs. For the above spectral models, the bulk of the luminosity is in the 0.5–10.0 keV band; for example, if the high energy limit of the band is extended from 10.0 to 100 keV, the luminosities for both the BH and NS SXTs are increased by $< 60\%$.

Table 2 shows the maximum luminosities L_{max} and minimum luminosities L_{min} observed for a number of NS SXTs and BH SXTs. The luminosities given here require a knowledge of the distances to the sources, which are somewhat uncertain. We therefore show in the final column of Table 2 the quantity L_{min}/L_{max}, which is independent of the distance. Because the blackbody temperatures of NS SXTs in quiescence are ~ 0.3 keV, the interstellar medium can absorb a significant fraction of the total flux. We have corrected for this absorption for both the NS and BH SXTs using the column densities (N_H) given in Table 2, which were derived (in most cases) using the relation of Predehl & Schmitt (1995) and the measured values of the optical reddening with $A_V = 3.1E(B-V)$. For a few of the NS SXT in outburst a higher N_H appears to be indicated, and was used (see Section 3.1). We note that these outburst luminosities are insensitive to errors in the assumed N_H.

3.1. Notes on Individual Sources

BH SXTs: The values of L_{max} correspond to the energy range 1–40 keV (Tanaka & Shibazaki 1996) except for H1705–25, for which the energy range is 2–200 keV (Wilson & Rothschild 1983). All of the luminosity limits are at the 3σ level of confidence. **GS2000+25:** We have combined three observations from the HEASARC database for a total exposure of 26.5 ksec. For E$(B-V)=1.5$ (e.g., Chevalier & Ilovaisky 1990), we find $\mathrm{N_H} = 8.3\times10^{21}\mathrm{cm}^{-2}$, which is substantially higher than the value assumed by Verbunt et al. (1994).

NS SXTs: The distances and values of the interstellar column, $\mathrm{N_H}$, are as summarized in Table 2, unless explicitly mentioned below. **X1608–52:** Asai et al. (1996) have measured a quiescent flux with ASCA which corresponds to a detected luminosity of 5×10^{32} erg s^{-1}(0.5–10 keV) and an emitted luminosity of 1.9×10^{33} erg s^{-1}(0.5–10 keV). Tenma has observed 2–20 keV luminosities as high as 3×10^{37} erg s^{-1} (Mitsuda et al. 1989). The high-state X-ray absorption is measured as $\sim 2\times10^{22}$ cm^{-2}, and may be higher than that observed in quiescence due to local absorption. The emitted 0.5–10 keV luminosity for the spectral shape and absorption quoted in Mitsuda et al. (1989) is 1.1×10^{38} erg s^{-1}. **Cen X–4:** The intrinsic, quiescent 0.5–10 keV luminosity has been measured with ASCA as 2.4×10^{32} erg s^{-1}(Asai et al. 1996). During its brightest transient outburst (excluding the peaks of type I X-ray bursts), Cen X–4 reached ~ 1000 c s^{-1} in the Ariel 5 ASM, which covered an energy range of 3–12 keV (Evans, Belian & Conner 1970). The corresponding 0.5–10 keV luminosity assuming a bremsstrahlung spectrum with $kT = 3.9$ keV is 1.2×10^{38} erg s^{-1}. **Aql X–1:** For the observed PSPC count rate of 0.03 c s^{-1} and a 0.3 keV black body spectrum (Verbunt et al. 1994), we calculate a 0.5–10 keV luminosity of 4.4×10^{32} erg s^{-1}. The brightest outburst of Aql X–1 recorded to date was observed with Ariel 5, SAS–3, and Copernicus in 1978 (Charles et al. 1980). The temperature measured with Copernicus was ~ 9 keV. We calculate an unabsorbed 0.5–10 keV luminosity of 3.6×10^{37} erg s^{-1}. **EXO 0748–676:** In quiescence, Parmar et al. (1986) found an intrinsic 0.2–3.5 keV luminosity of 1.2×10^{34} erg s^{-1} and Garcia & Callanan (1997) determined a blackbody temperature of 0.2 keV. The intrinsic 0.5–10 keV luminosity is 1.2×10^{34} erg s^{-1}. The highest flux yet recorded from EXO 0748–676 is 1.5×10^{-9} erg cm^{-2} s^{-1}, 1–20 keV (Parmar et al. 1986). Assuming the spectra found by Parmar et al., we compute a 0.5–10 keV intrinsic luminosity of 3.3×10^{37} erg s^{-1}. **4U 2129+47:** Using a blackbody temperature of 0.22 keV (Garcia & Callanan 1997), we calculate an intrinsic 0.5–10 keV luminosity of 5.9×10^{32} erg s^{-1} in quiescence. Calculation of the intrinsic high state flux is complicated by the facts that (1) only a small fraction of the flux emitted by the neutron star is scattered into our line of sight (McClintock et al. 1982, White & Holt 1982), and (2) the mean on-state flux decreased steadily since discovery (Pietsch et al. 1986). The 0.5–10 keV high state luminosity computed assuming the two-component spectrum in Garcia (1995) is 9.1×10^{35} erg s^{-1}. Correcting for a scattering fraction of 4% (as measured in EXO0748–676, Parmar et al. 1986) and a factor of ~ 7 decrease in mean flux since discovery, we find a maximum intrinsic 0.5–10 keV luminosity of 1.6×10^{38} erg s^{-1}.

4. Conclusions

Figure 2 is a plot of L_{min}/L_{max} *vs.* L_{max} of the BH SXTs and NS SXTs discussed in §3. We see a clear confirmation of the basic ideas described in §2. First, the BH SXTs all have larger values of L_{max} than the NS SXTs, consistent with their larger masses. Also, none of the NS SXTs has $L_{max} > L_{Edd} = 2\times10^{38}$ erg s^{-1} (taking $M_{NS} = 1.4 M_\odot$). These facts have been noted before (e.g. Barret

et al. 1996).

Second, and this is new, without exception every BH SXT in Fig. 2 has a smaller value of L_{min}/L_{max} than every NS SXT. This is exactly what we expect if (1) BHs have horizons and NSs do not, and (2) quiescent SXTs accrete via ADAFs. Note that for some of the BH SXTs we only have upper limits on the quiescent luminosity. When these fluxes are ultimately measured, the difference between NS SXTs and BH SXTs may become even more dramatic.

Could the difference in L_{min}/L_{max} merely mean that NS SXTs experience a smaller range of $\dot{m}$ between quiescence and outburst compared to BH SXTs? This is unlikely since the two systems are very similar in many respects. Furthermore, NS SXTs are, if at all, likely to have a *larger* swing of $\dot{m}$ than BH SXTs. If a NS has a strong enough magnetic field and spins rapidly enough, the field can cause the accreting matter to be flung out through a "propeller effect" (Illarionov & Sunyaev 1975), thereby dimming the source. Asai et al. (1996) and Tanaka & Shibazaki (1996) have argued for the propeller effect in the NS SXT Cen X–4 in quiescence. If many quiescent NS SXTs undergo the propeller effect, the swing of luminosity between L_{min} and L_{max} will be enhanced in NS SXTs as a class. BHs, on the other hand, cannot have a propeller effect because of the "no-hair" theorem which rules out a permanent magnetic field on a BH (Shapiro & Teukolsky 1983). Since the presence of the propeller effect in quiescent NS SXTs would tend to wash out the difference in L_{min}/L_{max} which we predict between NS SXTs and BH SXTs, the fact that the predicted difference is seen clearly in the data is especially significant.

Could BH SXTs appear less luminous by expelling most of their energy through outflows? This is possible in principle, but is somewhat contrived since we need a mechanism that is extremely sensitive to mass, switching on suddenly for accretors more massive than $1.4M_{\odot}$.

We suggest that the most natural explanation for the difference in luminosity swing between BH SXTs and NS SXTs is that BHs have event horizons and NSs do not. It is a basic property of a BH event horizon that it will hide any thermal energy which falls through it. A NS, on the other hand, does not have a horizon and must re-radiate whatever thermal energy it accretes. We suggest that Figure 2 confirms this difference. The argument presented here is robust since it makes use of one of the most basic observables in astronomy, namely the total received flux.

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REFERENCES

Abramowicz, M.A., Chen, X., Kato, S., Lasota, J.-P., & Regev, O. 1995, ApJ, 438, L37

Asai, K., Dotani, T., Mitsuda, K., Hoshi, R., Vaughn, B., Tanaka, Y., & Inoue, H., 1996, PASJ, 48, 257.

Barret, D., McClintock, J. E., & Grindlay, J. E., 1996, ApJ, 473, 963

Blair, W.P., Raymond, J.C., Dupree, A.K., Wu, C.C., Holm, A.V., & Swank, J.H. 1984, ApJ, 278, 270

Charles, P.A., et al. 1980, ApJ, 237, 154

Chen, X., Abramowicz, M. A., Lasota, J.-P., Narayan, R., & Yi, I. 1995, ApJ, 443, L61

Cowley, A.P., & Schmidtke, P.C. 1990, AJ, 99, 678

Evans, W.D., Belian, R.D., & Conner, J.P. 1970, ApJ, 159, L57

Frank, J., King, A., & Raine, D. 1992, Accretion Power in Astrophysics, (Cambridge: Cambridge Univ. Press)

Garcia, M.R., & Callanan, P.J. 1997, to be submitted to ApJ

Grindlay, J.E., & Liller, W. 1978, ApJ, 220, L127

Illarionov, A. F., & Sunyaev, R. A. 1975, Sov. Astr. Lett., 1, 73

Joss, P., & Rappaport, S. 1984, ARAA, 22, 537

McClintock J.E., London, R.A., Bond, H.E., & Grauer, A.D. 1982, ApJ, 258, 245

Mahadevan, R. 1997, ApJ, 477, in press

Mitsuda, K., Inoue, H., Nakamura, N., & Tanaka, Y. 1989, PASJ, 41, 97

Narayan, R., Barret, D., & McClintock, J. E. 1997, ApJ, submitted

Narayan, R., McClintock, J. E., & Yi, I. 1996, ApJ, 457, 821

Narayan, R., & Yi, I. 1994, ApJ, 428, L13

Narayan, R., & Yi, I. 1995, ApJ, 452, 710

Parmar, A.N., White, N.E., Giommi, P., & Gottwald, M. 1986, ApJ, 308, 199

Pietsch, W., Steinle, H., Gottwald, M., & Graser, U. 1986, A&A, 157, 23

Predehl P., & Schmitt, J. 1995, A&A, 293, 889

Rees, M. J., Begelman, M. C., Blandford, R. D., & Phinney, E. S. 1982, Nature, 295, 17

Schoembs, R., & Zoeschinger, G. 1990, A&A, 227, 105

Shapiro, S.L., Lightman, A.P., & Eardley, D.M. 1976, ApJ, 204, 187

Shapiro, S.L., & Teukolsky, S.A. 1983, Black Holes, White Dwarfs, and Neutron Stars, Wiley (1983)

Tanaka, Y., & Shibazaki, N. 1996, ARAA, 34, 607

Thorstensen, J., Charles, P., & Bowyer, S. 1978, ApJ, 220, L131

van Paradijs J., & McClintock, J.E. 1995, in X-ray Binaries, ed. W. H. G. Lewin, J. van Paradijs, E. P. J. van den Heuvel, Cambridge Univ. Press, 58

van Paradijs, J., Verbunt, F., Shafer, R.A., & Arnaud, K.A. 1987, A&A, 182, 47

Verbunt, F., Belloni, T., Johnston, H.M., v.d. Klis, M., & Lewin, W.H.G., 1994 A&A, 285, 903.

White, N.E., & Holt, S.S. 1982, ApJ, 257, 318

Wilson, C. K., & Rothschild, R. E. 1983, ApJ, 274, 717

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Table 1

Log of Observations of SXTs in Quiescence

Object	Detector	Date of Observation	Time (ksec)
Neutron Star SXTs			
EXO0748–676	Einstein IPC	1980 March 22	5.7
Aql X–1	ROSAT PSPC	1992 October 15–17	14.4
Cen X–4	ASCA GIS+SIS	1994 February 27–28	28.0
4U2129+47	ROSAT PSPC	1994 June 3	30.0
H1608–522	ASCA GIS+SIS	1993 August 12–13	32.0
Black Hole SXTs			
H1705–25	ROSAT HRI	1991 March 19–20	1.6
GS2000+251	ROSAT PSPC	1993 October 13	6.8
GS2000+251	ROSAT PSPC	1993 April 9–11	7.0
GS2000+251	ROSAT PSPC	1992 May 1–7	12.7
Nov Mus 91	ROSAT PSPC	1992 March 1–3	16.7
A0620–00	ROSAT PSPC	1992 March 10, 24–27	29.8
V404 Cyg	ASCA GIS+SIS	1994 May 9–10	40.0

Table 2

Luminosities of SXTs in Quiescence and Outburst

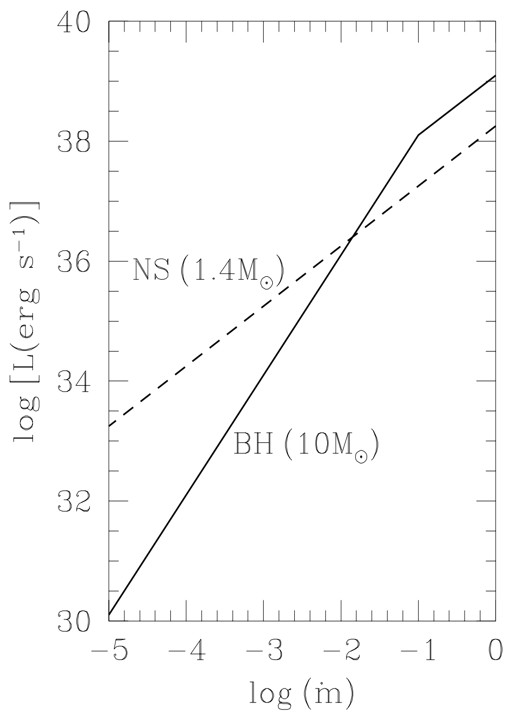
Object	D(kpc)	$\log(N_H)$	$\log(L_{min})$	$\log(L_{max})$	$\log(L_{min}/L_{max})$
			Neutron Star SXTs		
EXO0748–676	10.0[1]	22.35[2]	34.1	37.5	–3.4
Aql X–1	2.5[3]	21.32[3,4]	32.6	37.6	–5.0
Cen X–4	1.2[5]	20.85[6]	32.4	38.1	–5.7
4U2129+47	6.3[7]	21.20[7]	32.8	38.2	–5.4
H1608–522	3.6[5]	22.00[5,8]	33.3	38.0	–4.7
			Black Hole SXTs		
H1705–25	8.6[9]	21.44[10]	<33.7	38.3	<-4.6
GS2000+251	2.7[9]	21.92[10]	<32.3	38.4	<-6.1
Nov Mus 91	6.5[9]	21.21[10]	<32.6	39.1	<-6.5
A0620–00	1.2[9]	21.29[10]	31.0	38.4	–7.4
V404 Cyg	3.5[11]	22.04[12]	33.2	39.3	–6.1

References for Table 2: [1] Parmar et al. (1986) [2] Schoembs & Zoeschinger (1990), [3] Thorstensen, Charles & Bowyer (1978), [4] Verbunt et al. (1994), [5] Asai et al. (1996), [6] Blair et al. (1984), [7] Cowley & Schmidtke (1990), [8] Grindlay & Liller (1978), [9] Barret, McClintock & Grindlay (1996), [10] van Paradijs & McClintock (1995), [11] Tanaka & Shibazaki (1996), [12] Narayan et al. (1997)

Figure Captions

Figure 1. Expected variation of the luminosities of BH SXTs and NS SXTs as functions of the Eddington-scaled mass accretion rate $\dot{m}$ (based on Fig. 11 of Narayan & Yi 1995). The solid line corresponds to a $10M_{\odot}$ BH. For $\dot{m} > 0.1$, the accretion is assumed to take place via a thin disk with the standard 10% efficiency, while for $\dot{m} < 0.1$, the flow is assumed to be an ADAF with reduced efficiency. The dashed line corresponds to a NS SXT ($M_{NS} = 1.4M_{\odot}$), for which the efficiency is taken to be 10% regardless of the mode of accretion. Since $\dot{m}$ varies by a few orders of magnitude between outburst and quiescence, we expect BH SXTs to exhibit a substantially larger variation of L than NS SXTs. Figure 2 confirms this prediction.

Figure 2. The outburst luminosities L_{max} and luminosity ranges L_{min}/L_{max} of the NS SXTs (open circles) and BH SXTs (filled circles) listed in Table 2. Upper limits are indicated by arrows. We have left the BH SXT H1705–25 off the plot because the observation used to compute the upper limit on L_{min} is more than an order of magnitude less sensitive than the observations of the other 4 BH SXTs (see Table 1). The vertical dashed line represents L_{Edd} for a $1.4M_{\odot}$ NS. The horizontal dashed line is drawn to emphasize the point that every BH SXT has a lower value of L_{min}/L_{max} than every NS SXT. In the context of the ADAF model, this separation of BH SXTs and NS SXTs confirms that BH SXTs have horizons and NS SXTs do not.


40
38
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−4
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log [L(erg s^{-1})]
log ($\dot{m}$)
NS (1.4M$_\odot$)
BH (10M$_\odot$)

Figure 1

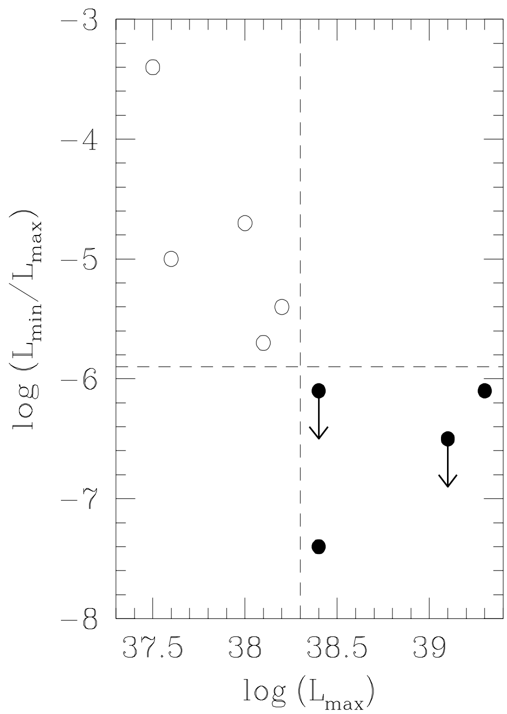

Figure 2